Search for sterile neutrinos as another research objective of θ_{13} experiments at reactors

V. Kopeikin[*], L. Mikaelyan[†], V. Sinev[‡]

Russian Research Centre "Kurchatov Institute", Moscow, Russia

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Abstract

Searches for mass-3 component in the electron neutrino flavor state $\sin\theta_{13}$ and for sterile neutrinos can be carried out in the same small mixing angle antineutrino oscillation experiment at a reactor. As an example we consider a layout, which involves several movable antineutrino spectrometers, stationed at distances 1700 m − 50 m from a reactor. The experiment can scan neutrino mass parameter interval $\sim$(0.5−0.001) eV^2 and have there typical sensitivity to $\sin^2 2\theta$ at a level of 0.015−0.02. The signature for sterile neutrino is disappearance observed at mass parameter Δm^2_{new} different from $\Delta m^2_{atm} \approx 2 \times 10^{-3}$ eV^2. In any case existing constraints both on $\sin\theta_{13}$ and on sterile neutrinos can considerably be improved.

Introduction

Discovery of sterile neutrinos would have a revolutionary impact on neutrino and particle physics.

Sterile neutrinos can hide, mimic or distort reactor antineutrino disappearance pattern in the atmospheric oscillation channel.

The notion of sterile neutrinos ν_s was originally introduced by B. Pontecorvo in 1967 y [1] and later has been considered by many authors: D. Caldwell and R. Mohapatra [2], S. Bilenky, C. Giunti and W. Grimus [3], K. Benakli and A. Smirnov [4], B. Kayser [5]. Information on theory of sterile (and mirror) neutrinos and references can be found in the recent paper by V. Berezinsky, M. Narayan, F. Vissani [6].

An experimental hint in favor of sterile neutrinos comes from unconfirmed observations of LSND collaboration [7] on $\nu_\mu \to \nu_e$ transitions.

[*]kopeykin@polyn.kiae.su
[†]mikaelyan@polyn.kiae.su
[‡]sinev@polyn.kiae.su

An idea how to look for sterile neutrinos at reactors along with $\sin\theta_{13}$ was proposed in Kurchtov Institute in 1998 y [8].

While solar, atmospheric, and laboratory (Super Kamiokande, SNO, KamLAND) studies are understood as only 3-active neutrino mixing (see however de Holanda, A. Smirnov, hep-ph/0307266) they do not exclude some admixture of sterile neutrinos.

1 How to search for sterile neutrios at reactors

In the 3-active neutrino mixing there are 3 masses and 3 mass parameters:

$$\Delta m^2_{12} = \Delta m^2_{solar} \sim (6-8)\times 10^{-5}\mathrm{eV}^2,$$
$$\Delta m^2_{atm} = \Delta m^2_{13} \approx \Delta m^2_{23} \approx 2\times 10^{-3}\mathrm{eV}^2 >> \Delta m^2_{solar}.$$

Antineutrino disappearance at distances L = 1000-2000 m from reactor source is governed by mass parameter Δm^2_{atm} and by mixing parameter $\sin^2 2\theta_{13}$:

$$P(\nu_e \to \nu_e) = 1 - \sin^2 2\theta_{13} \sin^2\left(\frac{1.27L\Delta m^2_{atm}}{E}\right). \tag{1}$$

In 3 active + 3 passive neutrino mixing there are 6 masses, 15 (!) mass parameters and a great number of mixing parameters.

It can quite happen that at least one of 12 new mass parameters Δm^2_{new} fells into the region $\Delta m^2_{new} \sim (0.5 - 1.0\times 10^{-3})$ eV^2.

It can be found there in the experiment of Kr2Det type [9] or its modification (some of them were discussed in 2002−2003 yy in Paris, Alabama and here at TUM), provided the associated mixing parameter $\sin^2 2\theta_s$ is not too small.

Antineutrino disappearance, found in a new channel Δm^2_{new} would mean existence of sterile neutrino(s).

Some part of the $\sin^2 2\theta - \Delta m^2$ plane is already excluded by the CHOOZ, Palo-Verde and Bugey experiments (shaded area in Fig. 1), vast left region is still to be explored.

2 Example of layout

Imagine that a tunnel is built near one 3.2 GW thermal power reactor. We consider five identically designed 30 ton target scintillator (movable) detectors, four of them stationed in the far position at a distance of 1700 m from the reactor, one 30 ton detector is stationed in the near position at 300 m from the reactor. To expand the explored mass parameter region towards larger values two small detectors are considered at 300 m and 50 m from the reactor.

Expected neutrino detection rates per 300 days are shown in Table 1

Table 1: Detector positions, scintillator target masses and $\bar{\nu}_e$ detection rates per 300 days.

Distance m	Target mass ton	$\bar{\nu}_e$rate/300day
50	5	1 100 000
300	5	30 000
300	30	190 000
1700	4 x 30	24 000

3 Analysis

Now instead of Eq. (1) we write:

$$P(\nu_e \to \nu_e) = 1 - \sin^2 2\theta_{13} \sin^2\left(\frac{1.27L\Delta m^2_{atm}}{E}\right) - \sin^2 2\theta_s \sin^2\left(\frac{1.27L\Delta m^2_{new}}{E}\right), \quad (2)$$

where θ_s and Δm^2_{new} refer to the sterile neutrino. We consider two types of data analysis: SHAPE and RATE. With ONE reactor as $\bar{\nu}_e$ source the SHAPE analysis (as we already know) is independent of exact knowledge of:

- Reactor power,
- Energy spectrum of $\bar{\nu}_e$ and its time variations,
- Target volumes and Proton concentrations,
- Absolute efficiencies of $\bar{\nu}_e$ detection.
- Backgrounds can periodically be measured.

The analysis based on comparison of the far/near $\bar{\nu}_e$ detection RATES requires good knowledge of Ratios of the target volumes and of Antineutrino detection efficiencies.

In both cases NO exact information from the reactor services on reactor power and fissile fuel composition is needed for data analysis.

4 Expected sensitivity

With 3 years of data taking (300 days/year) most part of the Δm^2 range (0.5-0.001) eV^2 can be searched for θ_{13} and sterile neutrinos with a sensitivity of $\sin^2 2\theta_{13}(\sin^2 2\theta_s) \sim 0.01 - 0.015 - 0.02$ which is in general agreement with the analysis performed by P.Huber, M.Lindner, T.Schwetz and W.Winter [10].

The limits shown in Fig. 3 were obtained assuming energy resolution $\sigma_E = 0.08\sqrt{E}$ and the systematics: $\sigma_{shape} = 0.5\%, \sigma_{rate} = 1\%$.

As can be seen in Fig. 3 the CHOOZ limit on $\sin^2 2\theta_{13}$ at $\Delta m^2_{atm} = 2\times 10^{-3}$ eV^2 can be improved by a factor 10.

5 Instead of discussions

Question: Should we look for sterile neutrinos in the θ_{13} experiments?

Probability P that we find them is low: $P \sim 0.001$

Importance I of finding steriles is very high: $I \sim 1000$

Argument in favor A:

$$A = P \times I \approx 0.001 \times 1000 = 1(!)$$

Answer: Yes, no doubt, we should look for sterile neutrinos.

6 Conclusions

Search for sterile neutrinos at reactors do NOT require much additional effort and can be done along with θ_{13}

With ONE Reactor and a number of detectors high sensitivity to θ_{13} and steriles can be reached.

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References

1. B. Pontecorvo, J. Exp. Theor. Phys. 53 1717 (1967). [Sov. Phys. JETP 26 984 (1968)].
2. D. Caldwell and R. Mohapatra, Phys. Rev. D 46, 3259 (1993).
3. S. Bilenky, C. Giunti and W. Grimus, Eur. Pys. J. C1, 247 (1998).
4. K. Benakli and A. Smirnov, Phys. Rev. Lett. 79, 4314 (1997).
5. B. Kayser, hep-ph/9810513.
6. V. Berezinsky, M. Narayan, F. Vissani, Nucl. Phys. B 658 (2003) 254.
7. LSND Collaboration, Phys. Rev. Lett. 81 (1998) 1774.
8. L. Mikaelyan, V. Sinev, Phys. At. Nucl. 62 (1999) 2008, hep-ph/9811228.
9. 4. L. Mikaelyan, V. Sinev, Phys. Atom. Nucl. 63 1002 (2000), (hep-ex/9908047); L. Mikaelyan, Nucl. Phys.B (Proc. Suppl.) 87 284 (2000); hep-ex/9910042; Nucl. Phys. B (Proc. Suppl.) 91 120 (2001), (hep-ex/0008046); V.Martemyanov et al., hep-ex/0211070.
10. P.Huber, M.Lindner, T.Schwetz and W.Winter in hep-ph/0303232.

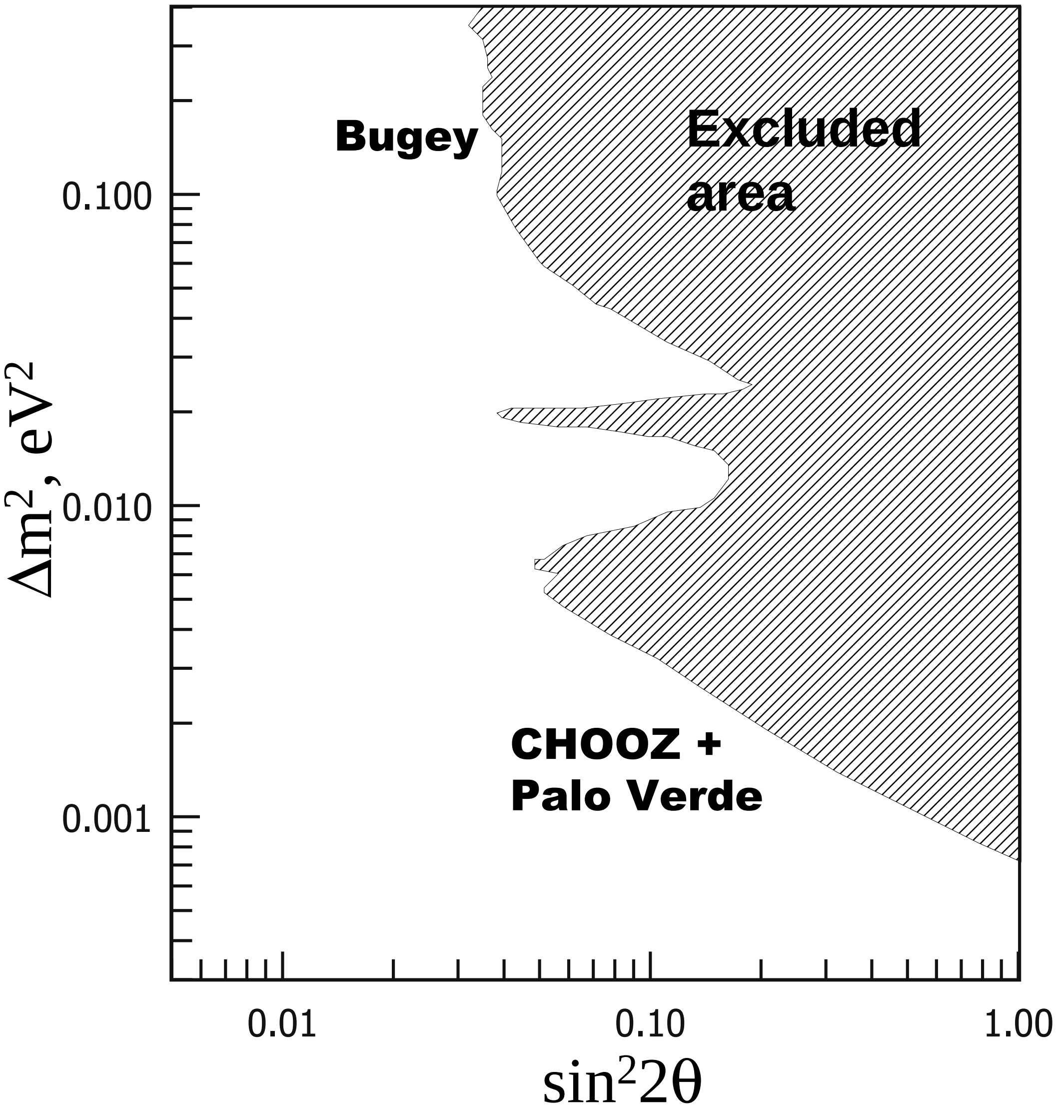

Fig 1. Present oscillation limits. Shaded area is excluded at 90% C.L.

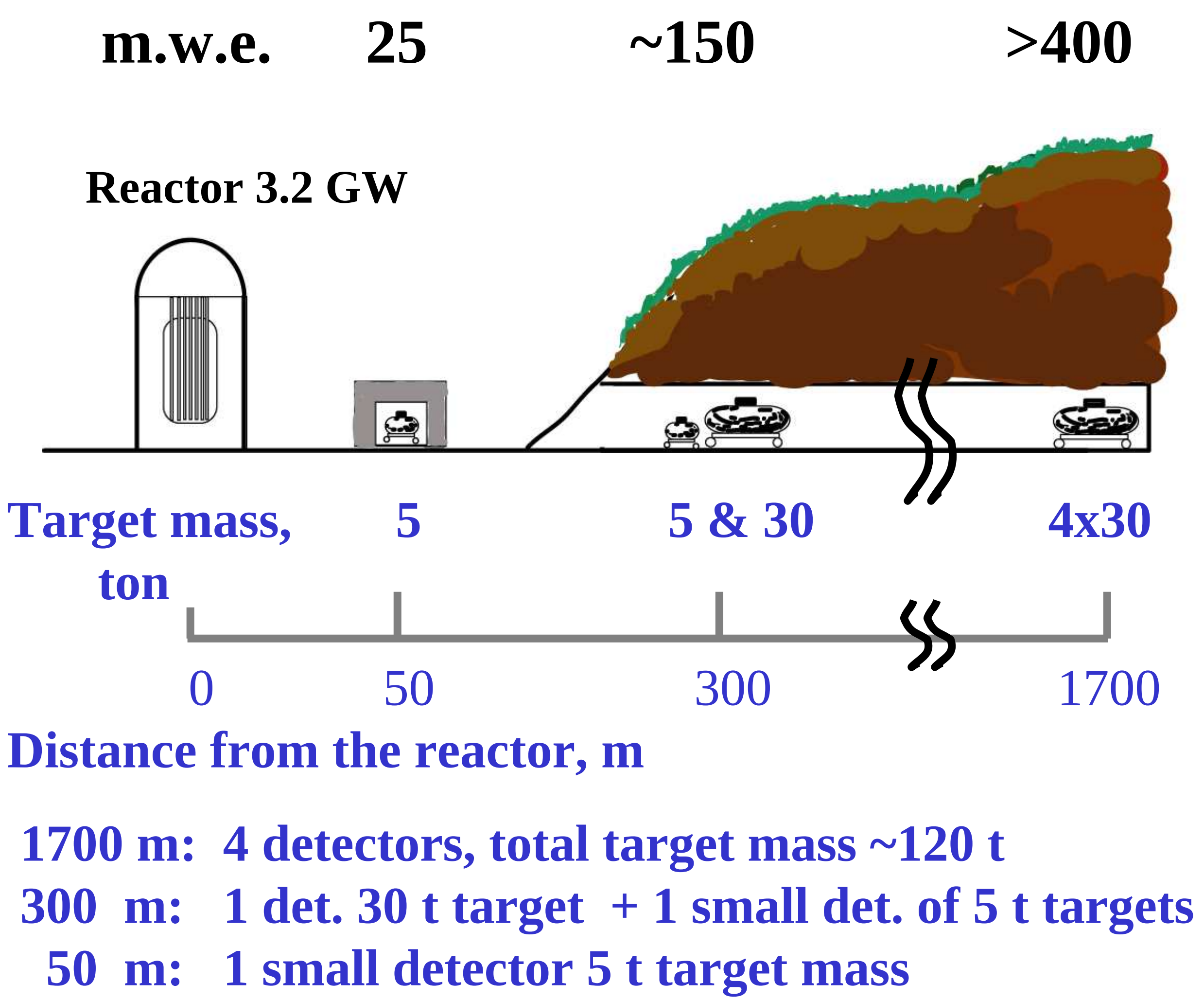

Fig. 2. Example of a layout. Detector positions, target scintillator masses and overburden (m.w.e.) are shown

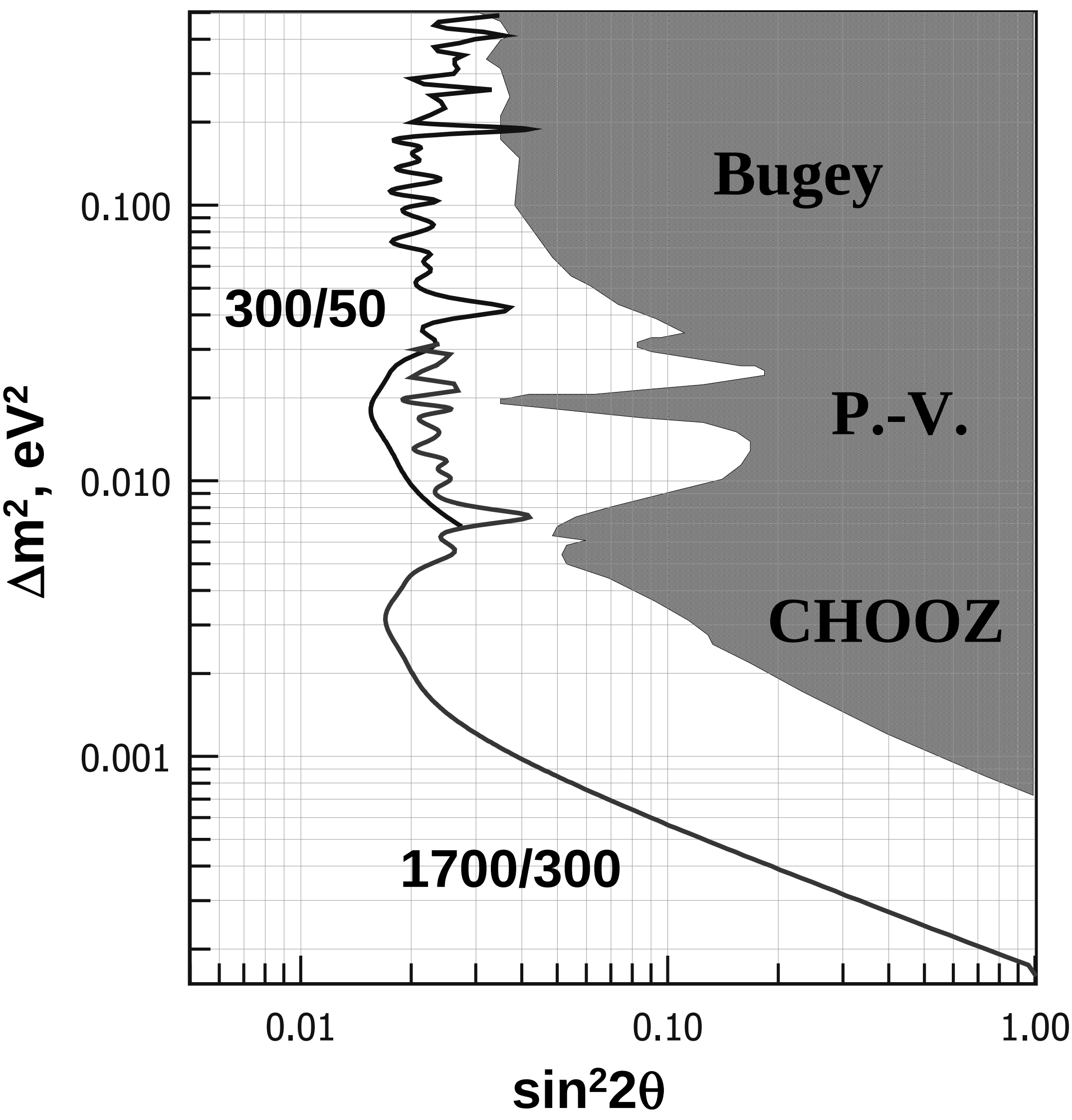

Fig. 3. Expected oscillation 90% C.L. limits